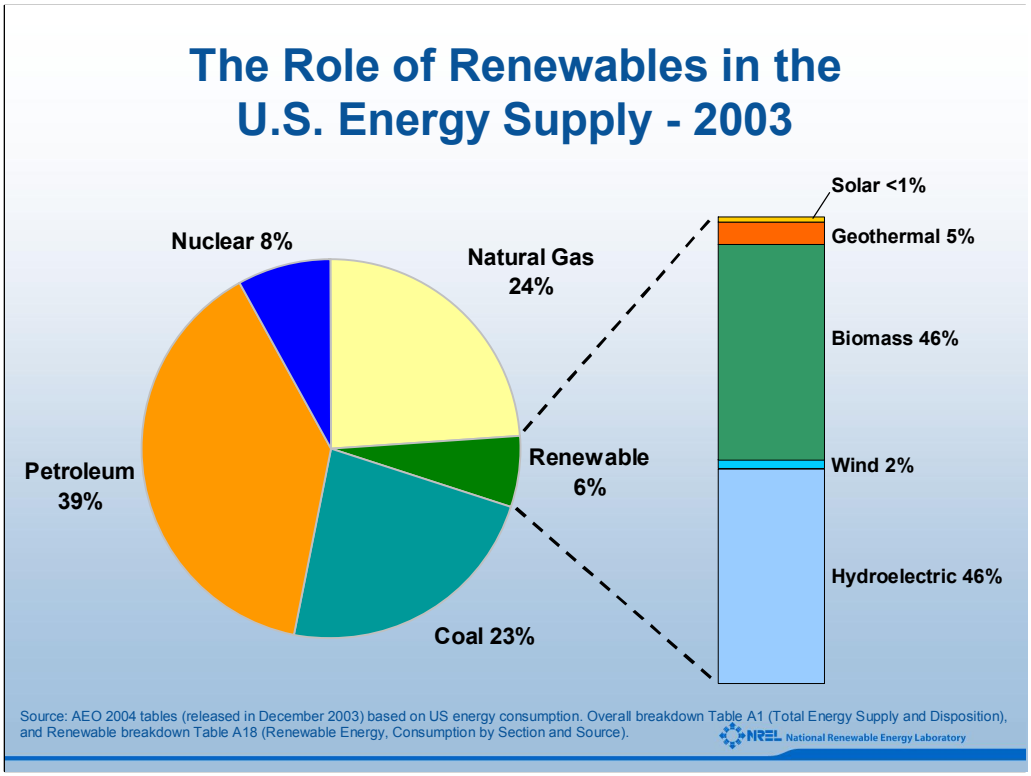
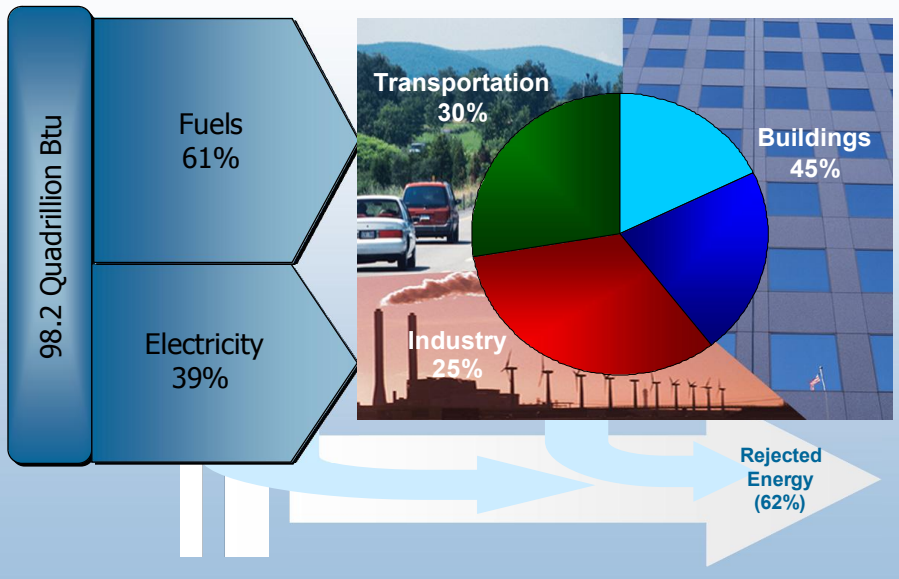

NREL National Renewable Energy Laboratory
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Innovation for Our Energy Future
Renewable Energy:
Strengthening Our Nation's Economy
Presented at the
Southern California Energy Conference
March 10, 2006
Dr. Michael A. Pacheco
Director, National Bioenergy Center
National Renewable Energy Laboratory



Data from preliminary AEO 2004 tables (released in December 2003). The data is based on US energy consumption (not production which is significantly different). Overall breakdown is from Table A1 (Total Energy Supply and Disposition). Renewable breakdown is from Table A18 (Renewable Energy, Consumption by Section and Source). Corn starch (3% of total renewable energy) and MSW (6% of total renewable energy) are both considered "Biomass" for this breakdown. Mark Ruth

U.S. Energy Flows



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Energy Challenges are Enormous

Energy Security and Reliability

Economic Growth

Natural Disasters

Environmental Impact

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Technology-based Solutions:

There is no single nor simple answer

- Energy efficiency
- Renewable energy
- Non-polluting transportation fuels
- Separation and capture of CO_2 from fossil fuels
- Next generation of nuclear fission and fusion technology
- Transition to smart, resilient, distributed energy systems coupled with pollution-free energy carriers, e.g. hydrogen and electricity

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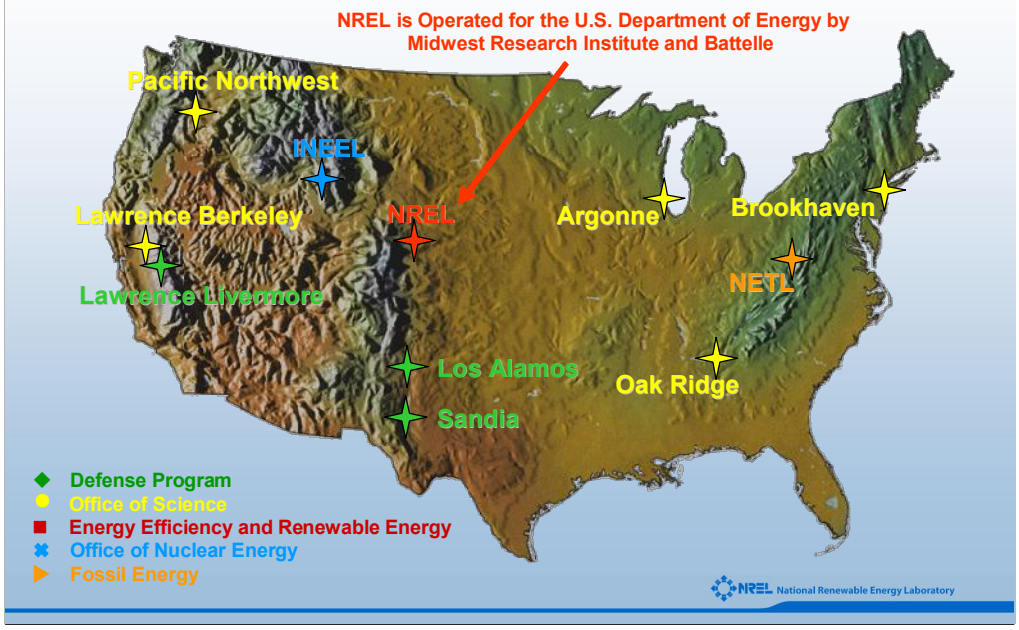
Major DOE National Laboratories



National Renewable Energy Laboratory

- Only national laboratory ***dedicated*** to renewable energy and energy efficiency R&D
- Research spans fundamental ***science*** to ***technology*** solutions
- ***Collaboration*** with industry and university partners is a hallmark
- Research programs ***linked*** to market opportunities

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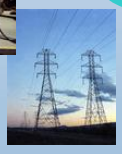
EERE's Technology Development Programs

Renewable Resources
- Wind
- Solar
- Biomass
- Geothermal

Efficient Energy Use
- Vehicle Technologies
- Building Technologies
- Industrial Technologies



Energy Delivery & Storage
- Electricity Transmission & Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

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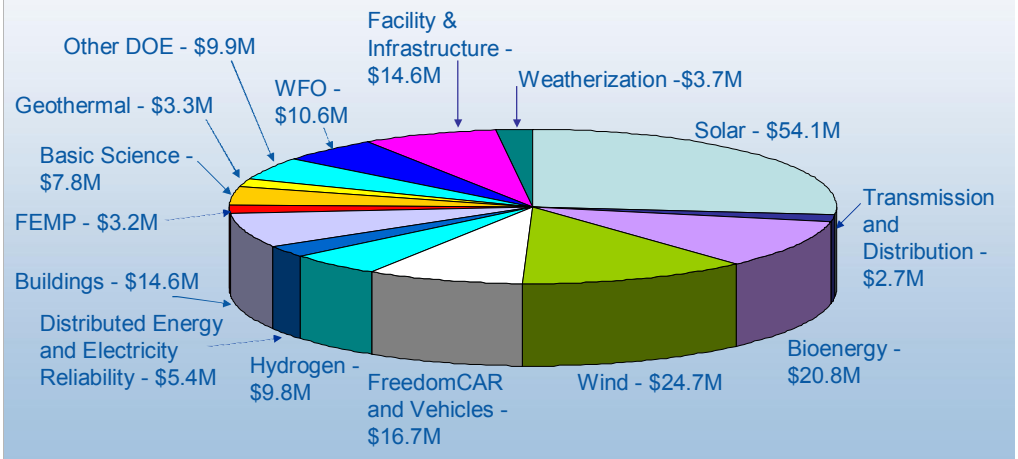
NREL FY 2005 Program Portfolio

$201.9 Million



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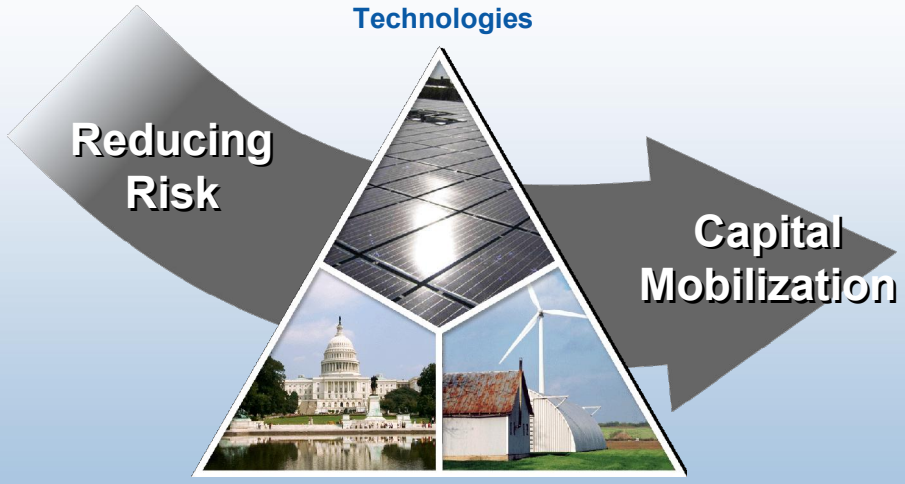
Getting There Involves…



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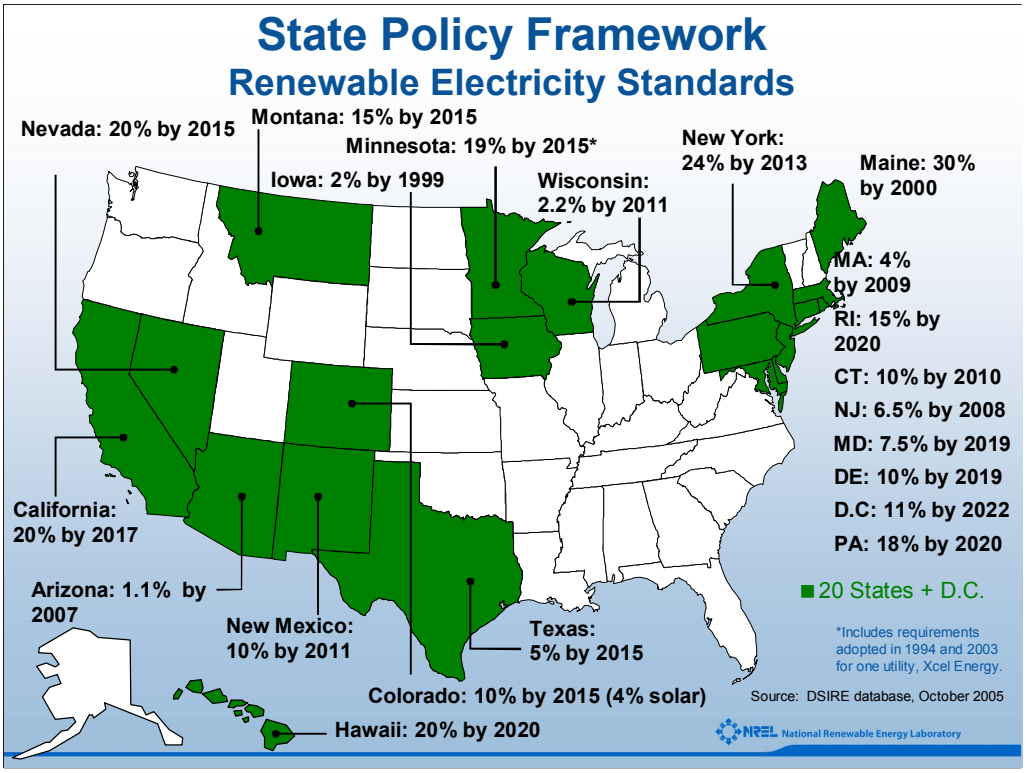
State Policy Framework
Renewable Electricity Standards
Nevada: 20% by 2015
Montana: 15% by 2015
Minnesota: 19% by 2015*
Iowa: 2% by 1999
Wisconsin: 2.2% by 2011
New York: 24% by 2013
Maine: 30% by 2000
MA: 4% by 2009
RI: 15% by 2020
CT: 10% by 2010
NJ: 6.5% by 2008
MD: 7.5% by 2019
DE: 10% by 2019
D.C: 11% by 2022
PA: 18% by 2020
California: 20% by 2017
Arizona: 1.1% by 2007
New Mexico: 10% by 2011
Texas: 5% by 2015
Colorado: 10% by 2015 (4% solar)
Hawaii: 20% by 2020
20 States + D.C.
*Includes requirements adopted in 1994 and 2003 for one utility, Xcel Energy.
Source: DSIRE database, October 2005
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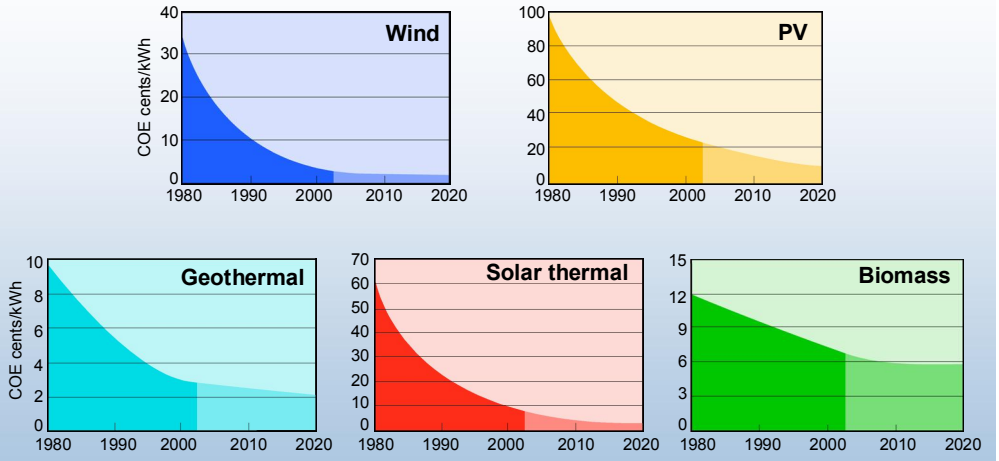
Renewable Energy Costs are Decreasing

Levelized cents/kWh in constant $2000[1]



Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2002.ppt)
[1]These graphs are reflections of historical cost trends NOT precise annual historical data.
Updated: October 2002

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Solar/Photovoltaics

Status:
- 150 MW
- Cost 20-30¢/kWh

Potential:
- 2020 goal: 6¢/kWh

NREL Research Thrusts
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

Source: U.S. Department of Energy

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Solar Outlook

Technology

DOE Solar Program goals:

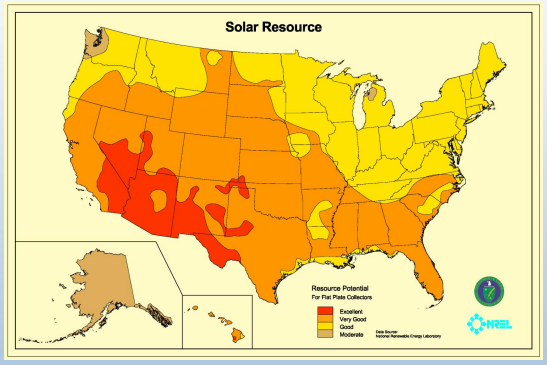
- PV: 6¢/kWh by 2020
- CSP: 5¢/KWh by 2012

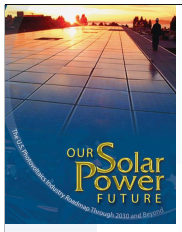
Policy

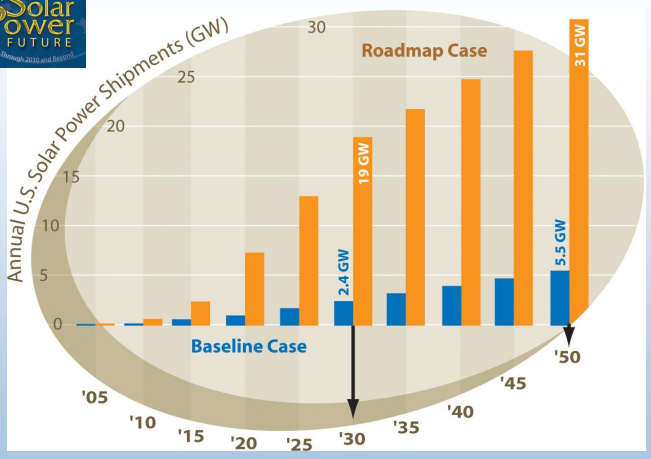
- 1000 MW initiative
- Western Governors' Association 30,000 MW by 2020 initiative
- State RPS with solar set asides

Market

- Peak power prices
- Green markets







Future Technology Directions

- Research on crystalline silicon, thin films, and balance-of-systems components
- Higher-risk, longer-term R&D for all system components that can leapfrog beyond today's technology
- Partnerships among industry, universities, and national laboratories

Comparison of annual U.S. solar power shipments under the Baseline and Roadmap cases. Shipments in 2030 and 2050 are 2.4 and 5.5 GW for the Baseline case and 19 and 31 GW for the Roadmap case.

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Wind

Status:
- 9,200 MW
- Cost 4-6¢/kWh (unsubsidized)

Potential:
- 3¢/kWh (onshore) by 2012
- 5¢/kWh (offshore) by 2012

NREL Research Thrusts
- Low-windspeed turbines
- Advanced power electronics
- Technology transfer to ocean-based systems

Source: U.S. Department of Energy, American Wind Energy Association

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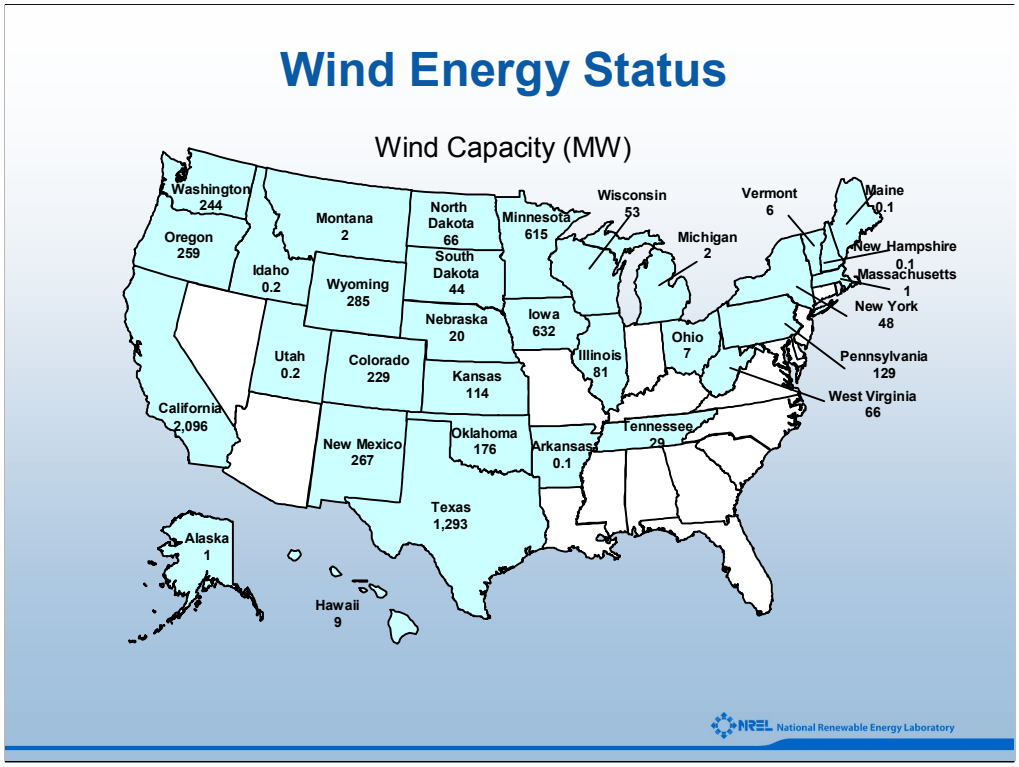


•US wind energy capacity tripled in past decade, 6770 MW today

•Commercial wind energy systems are currently installed in 27 states.

•Major drivers for this development include:

- Production tax credit

-State renewable portfolio standards

Advances in technology that are reducing turbine costs and lower siting risks

Wind Outlook

Technology

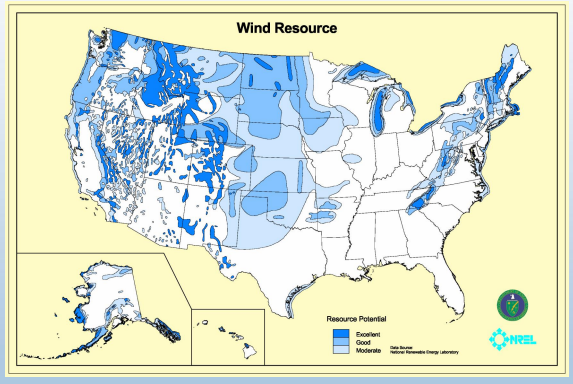
- DOE Wind Program R&D goals
  - 3¢/kWh* in class 4+ wind areas onshore
  - 5¢/kWh* for offshore systems
- New Technology will
  - Expand range of feasible sites
  - Reduce siting risk
  - Enhance system value

Policy

- State-led RPS
- Production Tax Credit

Market

- Natural gas prices
- Green purchasing



* unsubsidized

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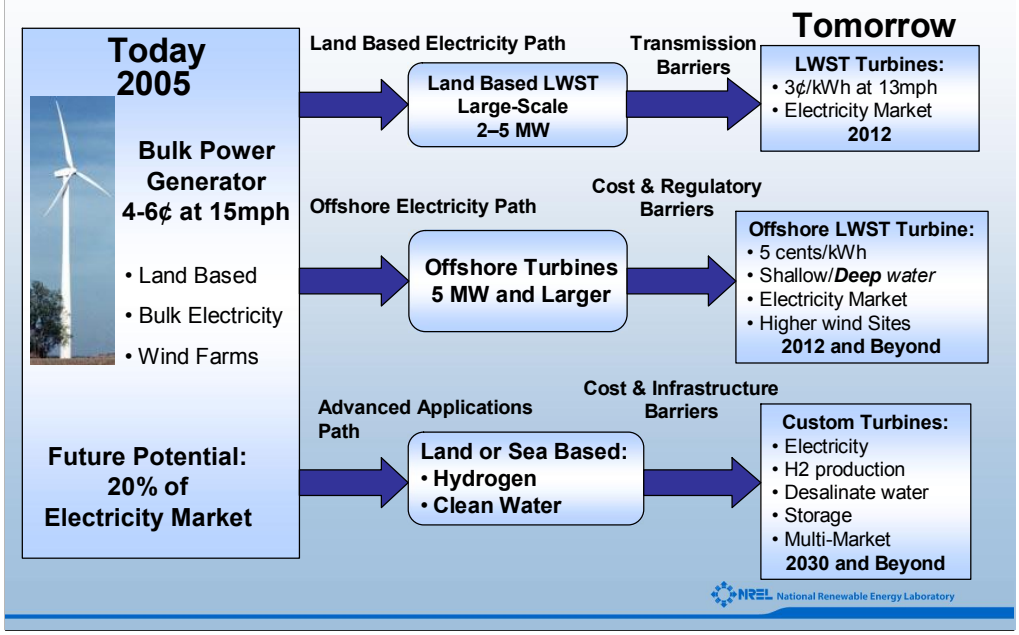
•Larger turbines and turbines built for low wind speed regimes will will expand applications to lower wind speed class in land based applications – typical of the American U.S. and stimulate offshore installations

A Future Vision for Wind Energy Markets



Biomass/Biofuels Status

Biopower

- Grid-connected capacity
  - 9700 MW direct combustion
  - 400 MW co-firing
- Biopower electricity prices generally range from 8-12¢/kWh

Biofuels

- Biodiesel –
  - 75 million gallons (2005)
- Corn ethanol -
  - 91 commercial plants
  - 4.3 billion gallons (2005)
  - ~$1.20/gal
- Cellulosic ethanol (not commercial)
  - Est. $2 - $3 /gal

Source: U.S. Department of Energy

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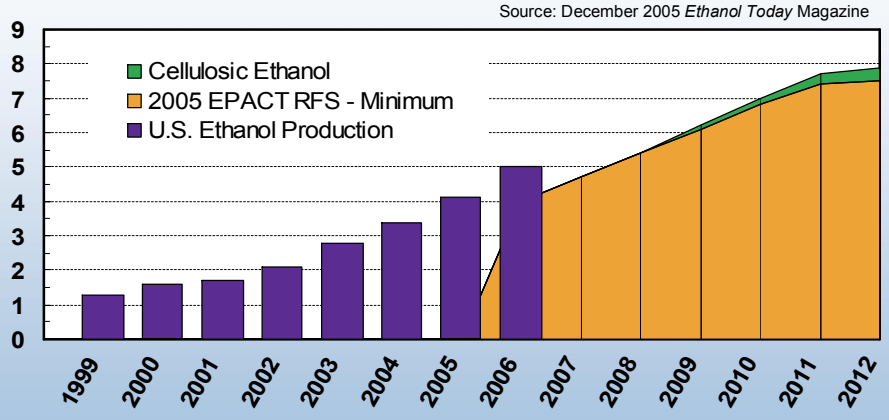
U.S. Ethanol Production

Actual and Projected U.S. Ethanol Production 1999-2012

Billion Gallons of Production

Source: December 2005 *Ethanol Today* Magazine



- Renewable Fuels Standard mandates 7.5 billion gallons by 2012
- Total US gasoline market ~140 billion annual gallons

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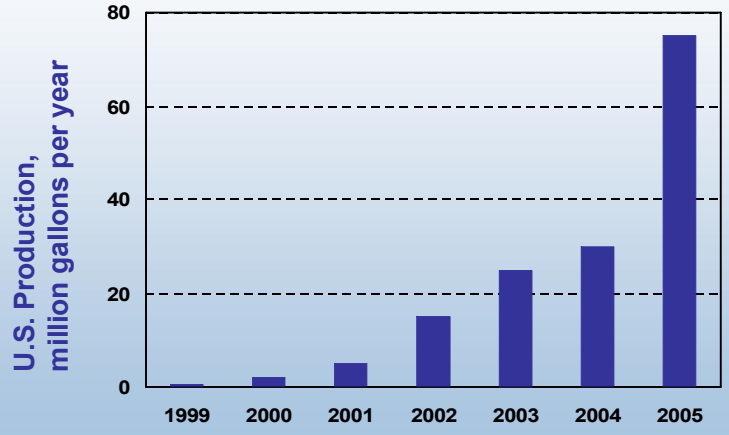
U.S. Biodiesel Production

Source: http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf (2-5-2006)



Total US distillate fuels market is approximately 60 billion gallons/year

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Biomass Outlook

Technology

DOE Biomass Program goals:

- 5.5¢/kWh by 2010
- $1.07/gal bioethanol by 2012

Policy

Biofuel tax incentives

Energy Policy Act of 2005 requires 7.5 billion gallons per year by 2012

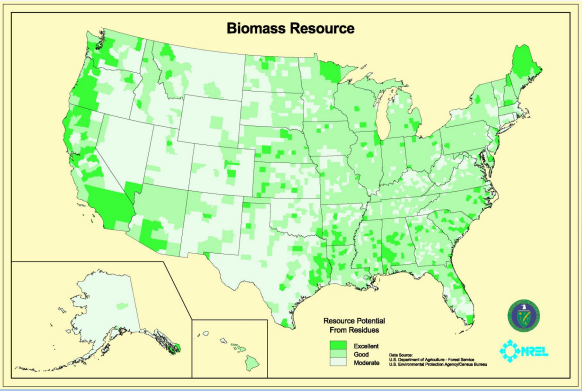
President's Biofuels Initiative

Market

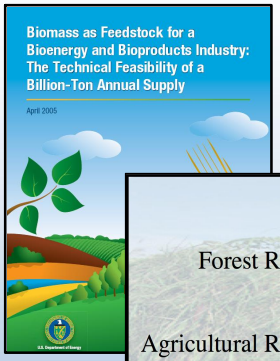
Growth in E85 stations

GM "Buy Yellow" campaign

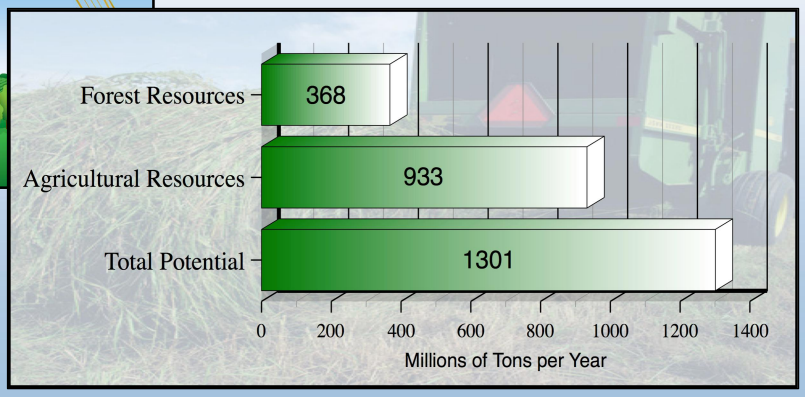
2030 goal: biofuels = 30% of transportation fuels



U.S. Biomass Resource Assessment



- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the "Billion Ton Study"



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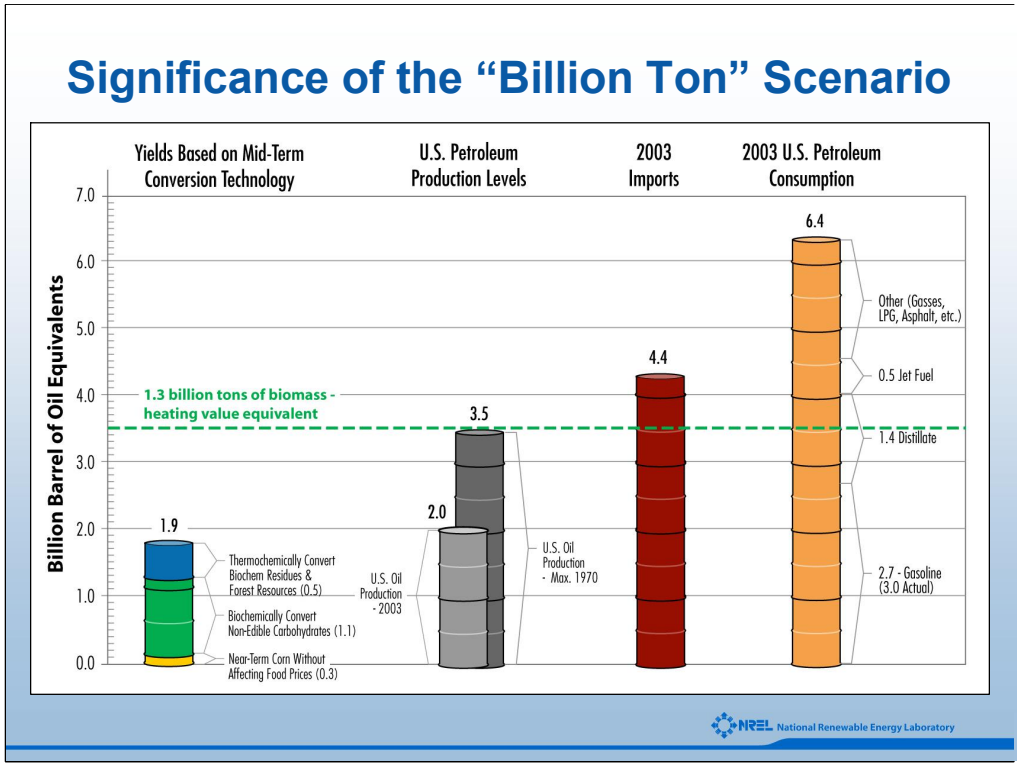


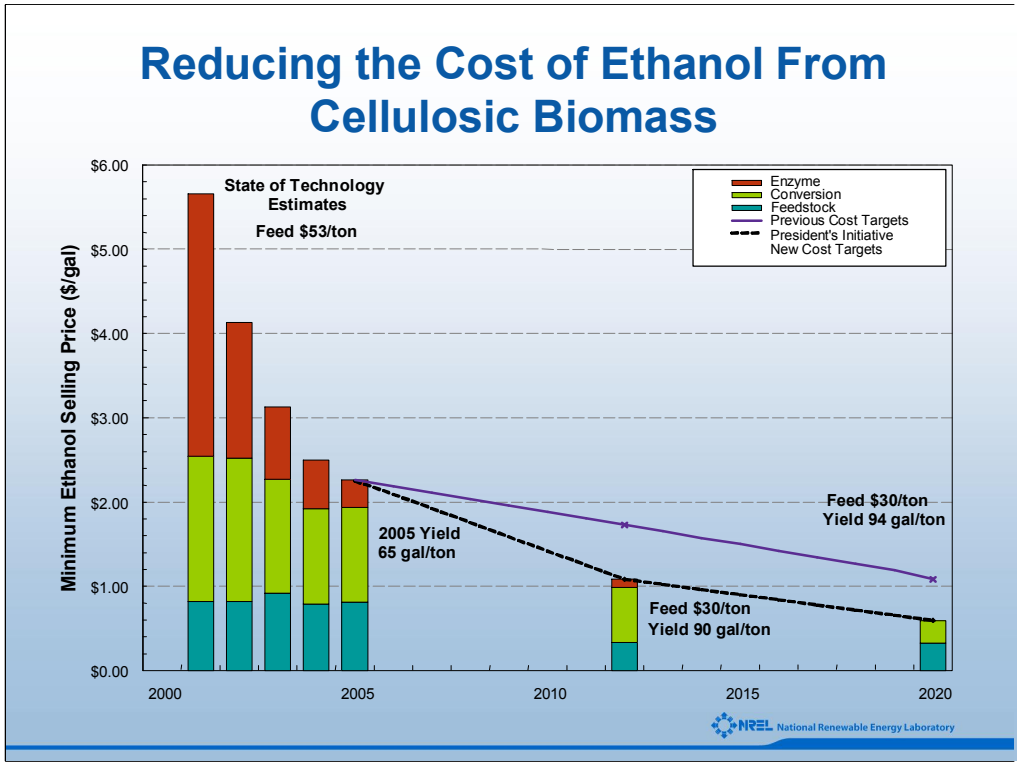
ORNL and USDA very recently issued a report describing a scenario for producing 1.3 billion tons of biomass every year in th U.S. This slide puts the recent ORNL-USDA *Billion Ton Vision Study* in context of petroleum displacement. For the green dashed line… energy contents of biomass were based on Higher (Gross) Heating Values, dry weight.

For near-term grains based on a very aggressive 20 billion gal ethanol per year as per estimate of NCGA. 2005 capacity is 4.4 billion gal. For mid-term conversion technologies of lignocellulosic biomass are assumed. 90 gal EtOH per ton of biomass (as per NREL's 2002 Design Report's Market Target). 72 gal EtOH per ton of biomass via thermochem (as per Rich Bain's Feb. 9, 2005 NREL tech memo). Includes all forest residues.

Lignocellulosic biomass yields are based on "today's technology", assuming alcohol production. Further improvements in Conversion Efficiency and/or alternative end products can dramatically change the impact biomass can have on displacing petroleum.

Currently, we use over 6 billion barrels of oil each year in the U.S. (Note: accounting differences depending upon whether including imported refined products, crude oil to Strategic Reserve, etc.). The United States (including Alaska) currently produces about 2 billion barrels of oil per year, only 67% of the U.S. biomass potential. U.S. oil production peaked in 1970-71 at approx 3.5 billion barrels per year. The U.S. has NEVER produced more than 3.5 billion barrels/year of oil.

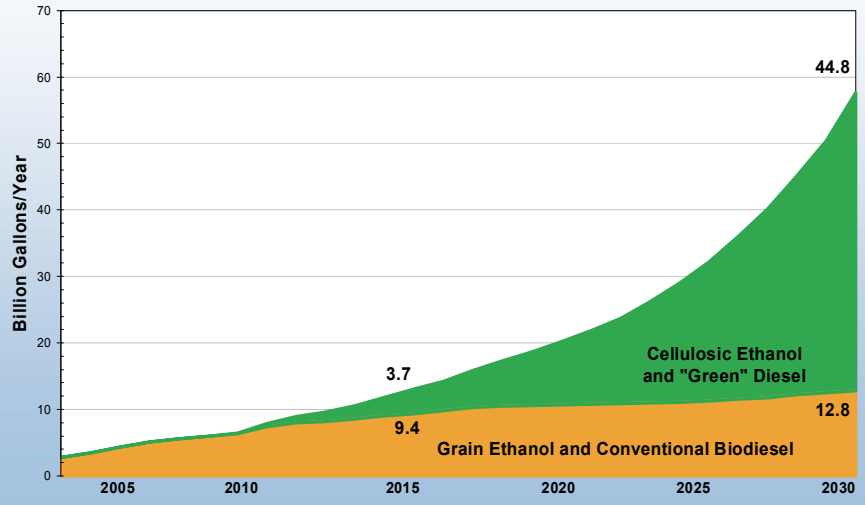
Energy content of biomass determined from the split of biomass type in Billion Ton Vision report. Note: No MSW was included in the billion ton vision. U.S. produces about 200 million ton/yr of MSW.



Over the past 5 years, tremendous progress has been made at reducing the cost of ethanol from cellulosic biomass, corn stover in particular, via the enzymatic hydrolysis pathway. In the late 1990's, the high cost of cellulase enzymes made it impractical to consider the use of these enzymes in hydrolyzing cellulose, despite the higher sugar yields that enzymes can provide over acid hydrolysis. In fact, acid hydrolysis was the norm at that time despite it's inherent yield limitations.

All that has changed due to a 4 year partnership between DOE/NREL and 2 of the world's largest enzyme manufacturers – Genencor and Novozymes. As shown in the chart, the cost of these enzymes has been reduced from over $3/gallon of ethanol, to now less than 25 cents per gallon. This is shown by the red segment in the stacked bar chart. Today, as a result of this DOE/NREL-industry 4-year partnership. All major process development for cellulosic ethanol is based on enzymatic hydrolysis of the cellulose, and the use of enzymes even for selective hydrolysis of the

Required Growth of Cellulosic Ethanol to Supply 30% of U.S. Gasoline Demand by 2030



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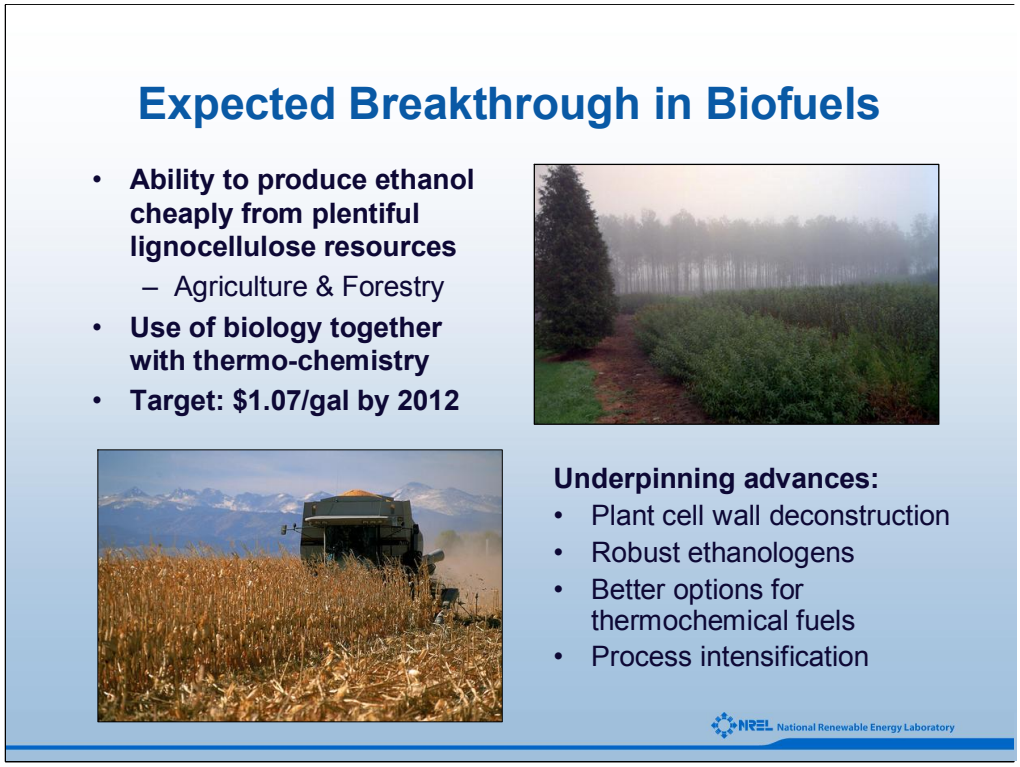
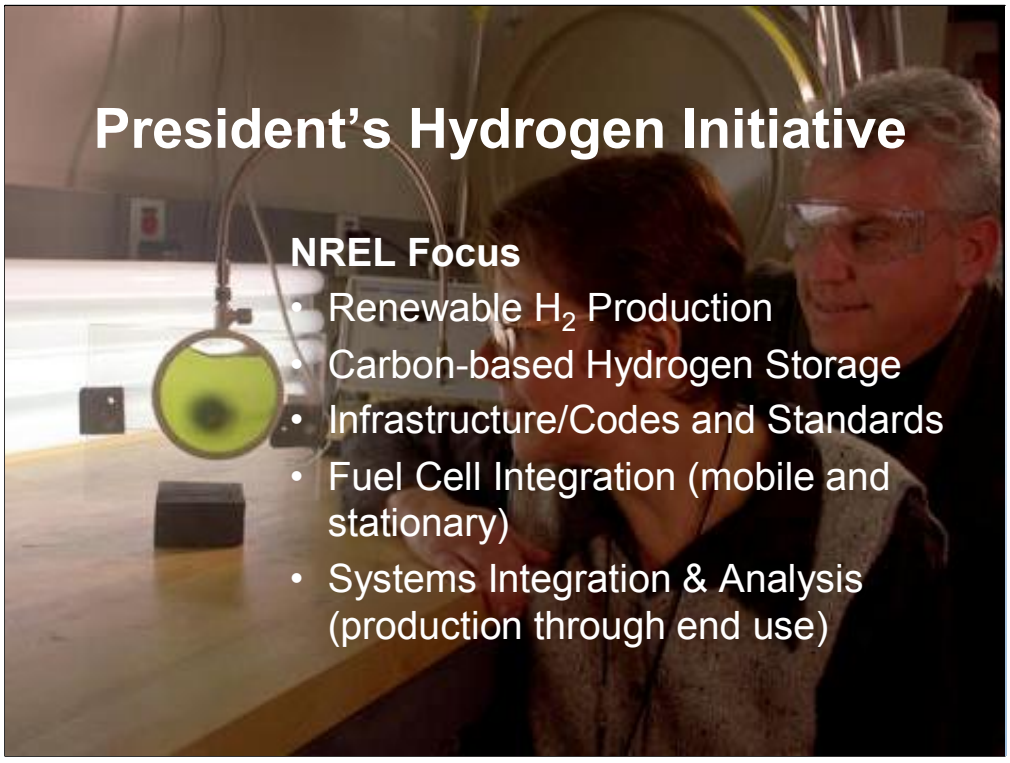


The largest breakthroughs expected in biofuels are:

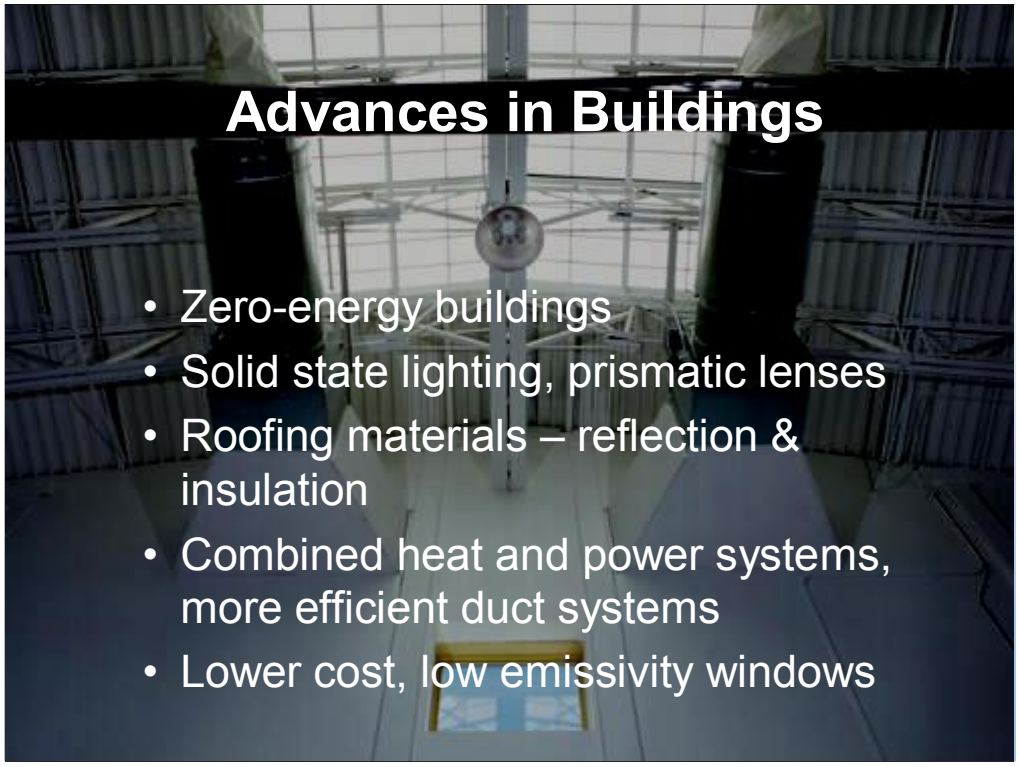
1) Our ability to cost-effectively produce ethanol from the complex carbohydrates (hemicellulose and cellulose) that comprise lignocellulosic biomass. … These carbohydrates represent the largest source of carbon based raw materials on the planet, and they are sustainably reproduced year after year. In fact, the flux of carbon cycling through land-based biomass on this planet is roughly ten times the flux of carbon due to our use of fossil fuels: 60 billion tons per year, versus 5.5 billion tons per year. Without biofuels from lignocellulose, biomass cannot significant impact petroleum usage in the U.S.
2) The combined use thermo chemistry together with biology will allow us to produce additional transportation fuels from the lignin fraction of biomass, and get acceptable yield and energy balance. In fact some biomass is so rich in things other than carbohydrates, that thermo chemistry may be the predominant source of liquid fuels. Lignocellulosic biomass typically stores 30-40% of it's heating value (energy content) as lignin, and this lignin is very difficult to convert biochemically.
3) The net affect of 1 & 2 will be to improve the overall yield and efficiency and reduce the cost of producing transportation fuels from biomass. DOE's target is $1.07 per gallon by 2020.

The underlying advances in technology that will enable these breakthroughs are:

- a dramatic improvement in our ability to cheaply deconstruct plant cell wall tissue into the simple C5 & C6 sugars,
- robust fermentation organisms, or ethanologens, that can convert the complex mixture of sugars from hemicellulose and cellulose into ethanol,


President's Hydrogen Initiative
NREL Focus
• Renewable H_2 Production
• Carbon-based Hydrogen Storage
• Infrastructure/Codes and Standards
• Fuel Cell Integration (mobile and stationary)
• Systems Integration & Analysis (production through end use)


Advances in Transportation (FreedomCAR)
• Transition – hybrids, then fuel cells
• More efficient vehicles
• Cleaner, higher BTU fuels
• Redesigning passenger environment for maximum efficiency and comfort
• Smart urban growth


Advances in Buildings
• Zero-energy buildings
• Solid state lighting, prismatic lenses
• Roofing materials – reflection & insulation
• Combined heat and power systems, more efficient duct systems
• Lower cost, low emissivity windows

Energy Efficiency and Renewable Energy Technologies Can Drive Economic Development in California

NREL is a partner in the developing cost-effective renewable resources to support growth of renewable energy industries

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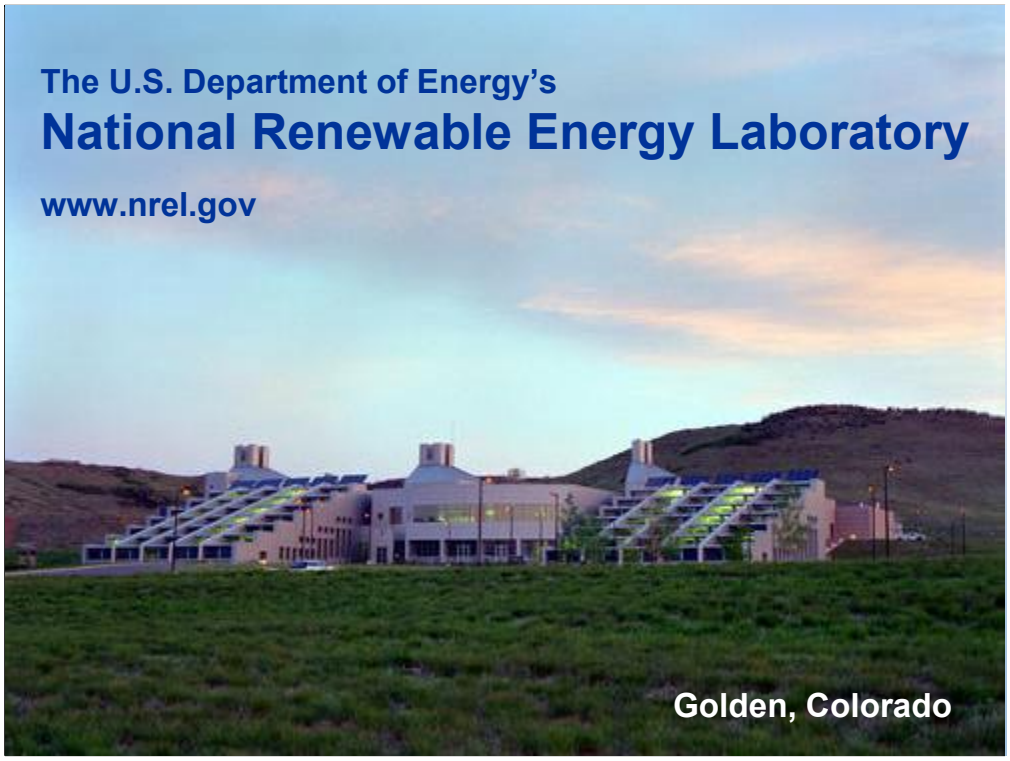
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